Deliberate Tracer Injections of Sulfur Hexafluoride on the West Florida Shelf in Support of:
An AUV-based Investigation of the role of Nutrient Variability in the Predictive Modeling of Physical Processes in the Littoral Ocean

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LONG-TERM GOAL

Our long-term goal is to explore and test the potential effectiveness of low-level nutrient concentrations (nitrate, nitrite, and ammonia) as descriptors of geophysical fields and tracers of physical processes in oligotrophic coastal waters. To test the validity of this approach, studies are performed using the deliberately injected inert tracer sulfur hexafluoride (SF6) and the advection and dispersion patterns of this tracer are compared with the patterns observed with the naturally occurring low-level nutrient concentrations. The SF_6 work includes development of sampling methods to characterize the tracer field with high spatial and temporal resolution in near real-time.

OBJECTIVES

The deliberate tracer sulfur hexafluoride, SF_6 is utilized as a validation for use of low-level nutrients as descriptors of geophysical fields. SF_6 is a stable and inert man-made gaseous compound with no known hazardous environmental effects in water or air. The SF_6 studies offer three essential pieces of information:

- SF_6 serves as a marker for a true Lagrangian study of nutrient dynamics with focus on ammonia.
- It can be used to quantify of horizontal dispersion in the shelf region.
- It offers a qualitative assessment of spatial variability.

The SF_6 tracer in essence "freezes" the processes under investigation in space in this dynamic region on the Florida Shelf.

APROACH

A total of three cruises have been performed to date on the West Fl Shelf in different times of the year to obtain seasonal information on the advection and dispersion rates and the impact on nutrient dynamics. The latest cruise occurred in April 2000 and was the fifth in the Florida Shelf Lagrangian Experiment series [*Wanninkhof et al.*, 1997]. The previous cruises funded by ONR were performed in July 2000 (FLSE III) and in November 2000 (FSLE IV) in the PORTAL ECOHAB region. The SF_6 releases in the mixed layer served to show the influence of tidal currents and wind forcing, and resulting divergences, on the tracer and nutrient distribution.

The injections of SF_6 for each cruise were performed by bubbling it through gas permeable hose at approximately 9-m depth into a 2-km streak. The temperature and depth of injection were monitored during injection. About 2 mol of SF_6 (0.3 kg) was bubbled in, which is sufficient to follow the tracer for the duration of the 10-day experiment. An underway SF_6 system has been improved over this performance period to quantitatively determine SF_6 in surface water at 2-minute intervals. It uses a Liqui-Cel flow membrane contactor (Hoechst Celanese Corp.) to assure rapid equilibration between gas and water phase while keeping the phases physically separated. The system is calibrated with standards obtained from Scott-Marin and cross-referenced to traceable standards from NOAA/CMDL and Dr. Ray Weiss of SIO. The system is used to track the location and spreading of deliberately injected SF_6 tracer patch in order to study the movement and horizontal dispersion of the tagged water. The Liqui-Cel membrane contactor has a single pass efficiency of 50 to 80 %, which was determined from discrete samples taken from the same seawater line during the cruises. Because of transit time through the seawater line and analysis time, the lag time (distance) between location of sample and analyses is about 5 minutes (or about 500 m@ 3 Knot). The system is interfaced with a GPS receiver such that the output file can be produced in near real time that contains time, SF_6 concentration, and location information. This facilitates quick navigational adjustments during surveys of the patch.

For a vertically well-mixed mixed layer, as often is observed on the Florida shelf, the tracer is mostly homogeneous down to the bottom of the mixed layer. By accounting for the large-scale tidal motion, using a drogued GPS drifter, and performing surveys of the patch over time the second moment of growth of the patch in the mixed layer can be determined from which the apparent horizontal diffusivity is estimated [*Okubo*, 1971].

WORK COMPLETED

The third FSLE field study sponsored by ONR was successfully completed on the R/V Walton Smith. Based on the previous two field studies, the objectives were fine-tuned to investigate the vertical dispersion of the tracer patch more fully. The study was optimized to use SF_6 to study the ammonia (NH_4^+) dynamics on the shelf (see reports N00014-96-1-5024 and N00014-02-1-0240 of K. Fanning and J. Walsh). The study was executed on a cruise from Miami to St Petersburg with the study area located at 27˚ N, 83˚ W. About 2 mol of SF_6 (0.3 kg) tracer was injected in a 2-km streak during the third day at sea in a region with elevated NH_4^+ concentrations. This location was to the south of the previous injections and further removed from the NAVY 3 buoy which was the injection point for the previous studies. Intense surveys for the following 11-days showed the evolution of the tracer patch. Surface water SF_6 along with T and S measurements were made continuously along the cruise track. The SF_6 data has been reduced and initial interpretation has commenced along with comparisons with the previous studies.

RESULTS

The results form the three studies, for the first time provides observational evidence of the response of the coastal waters to wind forcing on 10-km space scales. Each of the studies had periods of alongshore winds from the North West and South East. North Westerly winds caused the tracer patch to move southwards and remain near the surface due to upwelling favorable conditions. The periods of SE winds caused down welling favorable conditions and in each of the studies we see examples of down welling events advecting the tracer below the mixed layer. These events appear to be localized and because of the shear between the top and bottom layer, the tracer patch can exhibit a distinctly different surface and bottom water manifestation.

Tracer surveys, interspersed with CTD casts, provided both a vertical and horizontal view of this evolution of the tracer patch. An example of the surface concentrations during the ninth day of the last study is shown in Figure 1. The tracer field evolved into a long elliptical patch with its major axis roughly in an EW direction. This orientation is slightly different from the previous cruises because of differing wind regimes where the orientation is along shelf in a NW-SE direction. The translation of the patch is on day 9 is about 30 km to the SW. Based on modeling studies and current meter records both the orientation and the translations are in agreements with surface wind and tidal forcing [*He and Wesiberg*, 2001; *Weisberg et al.*, 1996; *Weisberg et al.*, 2001]. The strong NW wind that blew during the first part of the FSLE V study will cause the water movement in the direction observed.

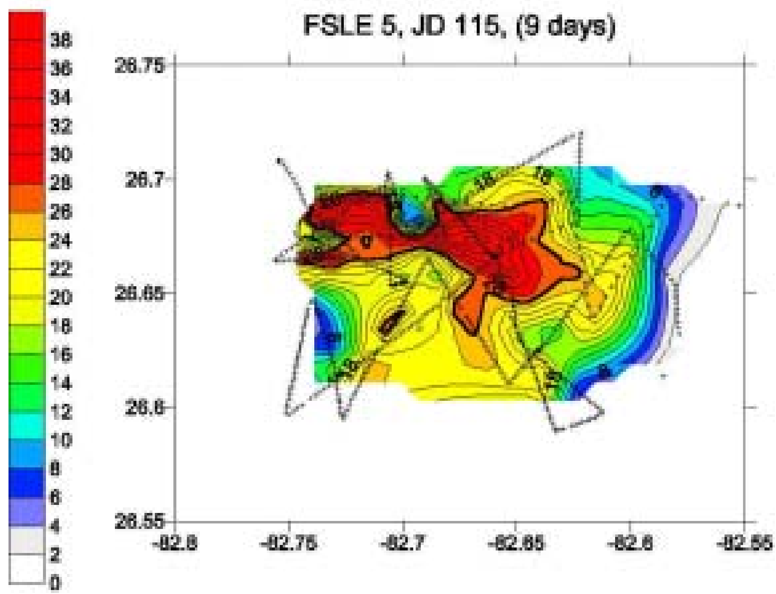

Fig 1. Contour plot of surface concentrations of SF_6 in part per trillion by volume (pptv) in the tracer patch 9-days after injection. The underway sampling locations along the cruise track are depicted by crosses. The injection took place about 30 km to the NW at 26.98 N, -82.82 W.

The vertical profiles obtained during the study shows an intricate pattern SF_6 in the water column with some evidence of enrichment in the benthic layer (Fig 2a). Several processes appear to be at work. Vertical eddy diffusion causes penetration downward. However, this cannot explain the higher concentrations near the bottom which must occur by (rapid) advective mixing during the SE wind that occurs immediately after NW wind. It is also apparent that vertical shear in the water column causes the surface, deep and benthic layers with their tracer to move relative too each other. Temperature profiles change significantly from day to day but the mixed layer has relatively homogeneous SF_6 profiles (Fig 2b). The fluorescence signal suggests higher chlorophyll below the mixed layer (Fig 2c).

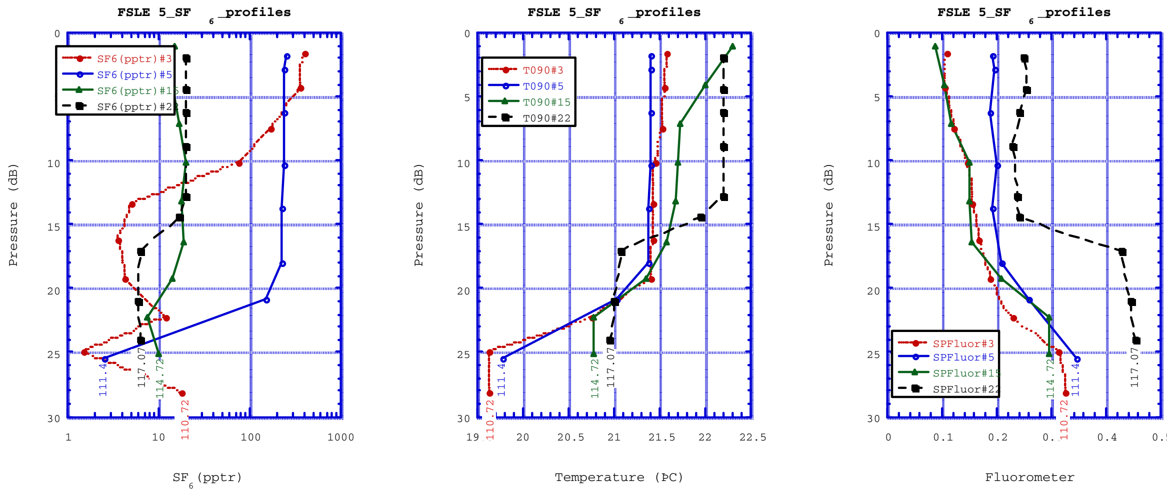

Fig 2. SF_6, temperature, and fluorescence profiles in the tracer patch 2, 3, 6, and 9 days after injection. The depth of injection was 9-m and the higher SF_6 concentrations near the bottom on JD110 and JD 114 (a) suggests that the penetration occurs at distinct downwelling zones. The temperature profiles (b) show significant day to day variations. In general, SF_6 is homogeneous within the mixed layer, except near the beginning of the study. The uncalibrated fluorometer signal (c) suggest higher chlorophyll concentrations below the mixed layer.

IMPACT/APPLICATION

The information from this field campaign is being compared with the Princeton Ocean Model (POM) set up by Prof. Weisberg of USF for the West Florida Shelf in order to verify model output and apply the observational findings to larger scale. In particular, the horizontal and vertical SF_6 concentrations and patch movement will be interpreted in the modeling framework. Close correspondence has been found between the observed displacement of the patch and modeled water movement. The NH_4^+ concentrations remained high in and near the tracer patch suggesting either an active but unknown source of NH_4^+ or that NH_4^+ is more stable than previously believed. If so, it could be powerful natural tracer of coastal mixing.

TRANSITIONS

The work performed during the FSLE 3, 4 and 5 studies points towards the need to further study variability on 1-km to 10-km scale and to obtain a better quantitative information on the extent of communication of waters in the surface mixed, deep and benthic layer. The tracer studies have unequivocally shown that there is exchange between the layers but this exchange must be limited, and possibly episodic, for the layers to maintain their unique physical and chemical structures. The upcoming study during FSLE6 (Nov 2- Nov 16, 2002) will focus on this aspect. This transition will require emphasis on improved near real-time sampling in the vertical either by towed undulating pumping systems.

RELATED PROJECTS

This study is part of a series of studies on the West Florida shelf to elucidate the physical forcing and chemical and biological transformations that occur on the shelf. The studies include the ONR AUV projects, the NOAA/EPA/ONR ECOHAB project, the mooring program and the ONR remote sensing and modeling efforts under HYCODE.

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